Digital Image Processing

- Digital image processing
  - Processing of digital images on a computer
    - Algorithms operate on input images to produce output images
    - Improvement for human interpretation
    - Processing for storage, transmission, and representation
  - Not just limited to the visual band of the electromagnetic spectrum
- Image analysis
  - Field of study in which algorithms operate on images to extract high-level information
- Image enhancement
  - Transforming an input image into another image to improve its visual appearance
- Image restoration
  - Restore an image that may have been corrupted by some type of noise
- Image compression
  - Manipulating an image so that the storage requires fewer bits than the original signal, while preserving the visual quality of the image
  - May be applied to still images or video
- Image segmentation
  - Analyzing an image to determine the pixels in an image that belong together, or that are part of the same object in a scene
  - Bottom-up process by looking at neighborhood of pixels
- Pixel classification
  - Analyzing an image to determine the pixels that belong to a predefined model
  - Top-down process relying on some system to facilitate a criterion to facilitate the creation of a model
- Shape from X
  - Recover the 3D structure of a scene using stereo, video, shading, or texture
  - Depends on linear algebra, projective geometry, and function optimization
- Machine vision
  - Systems in an industrial setting in which placement of the sensor and light source can be controlled
- Computer vision
  - Characterized by unstructured setting where placement of sensor and light source may not be controlled

History and related fields

- Newspaper industry
– Bartlane cable picture transmission system across Atlantic (1920s)
  www.hffax.de/history/html/bartlane.html
– Superseded by photographic reproduction from tapes using telegraph terminals
– Earlier images could code in five levels of gray, improved to 15 levels in 1929

● Figure 1.3

● Image analysis and computer vision
  – Areas based on image processing
  – Image processing outputs an image while image analysis and computer vision use image processing techniques to reason on images
  – Low-level processing
    * Both input and output are images
    * Image preprocessing operations such as noise reduction, contrast enhancement, and image sharpening
  – Mid-level processing
    * Inputs are images but outputs are characteristics extracted from those images, such as edges, contours, and identity of individual objects
    * Processing images to render them useful for further computer processing
    * Segmentation for object recognition and classification
  – High-level processing
    * Performing cognitive functions typically associated with human vision
    * Tracking or identifying objects in an image

Sample applications

● Space
  – Correction of distortion inherent in the onboard television camera on spacecraft
  – Remote earth observation and astronomy

● Medicine
  – Computerized axial tomography (CAT scan)
    – A ring of detectors circle the patient and an X-ray source, concentric with the detector ring, rotates about the patient
    – The sensed data is used to build a slice through the object
      * Numerous slices of patient’s body are generated as the patient is moved in a longitudinal direction
      * The slices are then combined to create a 3D rendering of the inside of patient’s body

● Robotics, including industrial inspection

● Document image analysis

● Transportation

● Homeland security, security, and surveillance

● Remote sensing

● Scientific imaging, plants and insects

● Entertainment
Examples of fields that use image processing

- Classification of images based on the source of energy, ranging from gamma rays at one end to radio waves at the other
- Viewing images in non-visible bands of the electromagnetic spectrum, as well as in other energy sources such as acoustic, ultrasonic, and electronic
- Gamma-ray imaging
  - Nuclear medicine
    * Inject a patient with a radioactive isotope that emits gamma rays as it decays
    * Used to locate sites of bone pathology such as infection of tumors
  - Positron emission tomography (PET scan) to detect tumors
    * Similar to CAT
    * Patient is given a radioactive isotope that emits positrons as it decays
    * When a positron meets an electron, both are annihilated giving off two gamma rays
  - Astrophysics
    * Studying images of stars that glow in gamma rays as natural radiation
  - Nuclear reactors
    * Looking for gamma radiation from valves
- X-ray imaging
  - Medical and industrial applications
    * Generated using an X-ray tube – a vacuum tube with a cathode and an anode
    * Cathode is heated causing free electrons to be released
    * Electrons flow at high speed to positively charged anode
    * Upon electron’s impact with a nucleus, energy released in the form of X-ray radiation
    * Energy captured by a film sensitive to X-rays
  - Angiography or contrast-enhanced radiography
    * Used to obtain images or angiograms of blood vessels
    * A catheter is inserted into an artery or vein in the groin
    * Catheter threaded into the blood vessel and guided to the area to be studied
    * An X-ray contrast medium is injected into the catheter tube
    * Enhances the contrast of blood vessels and enables radiologists to see any irregularities or blockages
- Imaging in ultraviolet band
  - Lithography, industrial inspection, microscopy, lasers, biological imaging
  - Fluorescence microscopy
    * A mineral fluorspar fluoresces when UV light is directed upon it
    * UV light by itself is not visible but when a photon of UV radiation collides with an electron in an atom of a fluorescent material, it elevates the electron to a higher energy level
    * The excited electron relaxes and emits light in the form of a lower energy photon in the visible light region
    * Fluorescence microscope uses excitation light to irradiate a prepared specimen and then, to separate the much weaker radiating fluorescent light from the brighter excitation light
    * Only the emission light reaches the sensor
    * Resulting fluorescing areas shine against a dark background with sufficient contrast to permit detection
  - Astronomy
• Visible and IR band
  – Remote sensing, law enforcement
  – Thematic bands in satellite imagery
  – Multispectral and hyperspectral imagery (Fig. 1.10)
  – Weather observation and monitoring
  – Target detection

• Imaging in microwave band
  – Radar

• Imaging in radio band
  – Medicine (MRI) and astronomy

• Other imaging modalities
  – Acoustic imaging (ultrasound), electron microscopy

Image basics

• Image
  – A discrete 2D array of values, like a matrix
    * Width of image is the number of columns in the image
    * Height of image is the number of rows in the image
    * Aspect ratio is width divided by height
  – A 2D function \( f(x, y) \)
  – \( x \) and \( y \) are spatial coordinates
  – Amplitude of \( f \) at a point is intensity or gray level of image at that point
  – Digital image
    * \( x, y, \) and \( f(x, y) \) are all discrete and finite
    * Finite number of elements with a given value at a location
      · Elements are called picture elements or pixels
  – Pixel coordinates may be represented using a vector notation
    * By convention, each vector is vertically oriented while its transpose is horizontally oriented
      \[
      \mathbf{x} = \begin{bmatrix} x \\ y \end{bmatrix} = [x \ y]^T = (x, y)
      \]

• Image storage into memory
  * Column major order
  * Row major order

• Accessing image data – origin at the top left corner
  * Scanline
  * Raster scan order
  * Image accessed as 1D array of pixels, with indices in the range \( i = 0, 1, \ldots, n \) where \( n \) is width \( \times \) height
* Relationship between 1D and 2D arrays

\[
i = y \cdot \text{width} + x \\
x = i \% \text{width} \\
y = i / \text{width}
\]

- Image types
  - Grayscale image
    * Pixel values quantized into finite number of discrete gray levels
    * Number of bits used to store each gray level known as bit depth
      - \( b \) bits imply \( 2^b \) gray levels
      - 8 bits per pixel gives 256 gray levels
      - Hexadecimal notation
      - Specialized applications may use more quantization levels to increase the dynamic range
  - RGB color image
    * Each pixel is a vector of three integers, representing three color channels
    * 24 bpp
      * Pixel vector stored as RGB or BGR
    * Values of different colors stored as interleaved channels as \( B_0G_0R_0B_1G_1R_1B_2G_2R_2 \cdots B_{n-1}G_{n-1}R_{n-1} \)
    * Other method for storage is planar layout, with each color channel stored separately
      \[ B_0B_1B_2 \cdots B_{n-1}G_0G_1G_2 \cdots G_{n-1}R_0R_1R_2 \cdots R_{n-1} \]
  - Alpha value or opacity
    * 00 indicates transparent while FF indicates opaque
  - Binary image
    * Each pixel is either black or white
    * 1 bpp, but displayed with 8bpp
      * Useful for building masks to separate areas of image
  - Real-valued image, or floating point image
    * 32-bit floating point number; 64-bit double precision values, 16-bit half-precision values
  - Complex-valued images
    * Output from computing the Fourier transform of an image

- Conceptualizing images
  - Brightness of each pixel proportional to its value
  - Raw pixels as a height map or 3D surface plot
  - \( I(x, y) \) as the value of the function at position \( (x, y) \)
  - Grayscale image as a matrix of pixel values
  - Color image as a matrix of 3-tuples
  - Binary image as the set of pixels with value 1

\[
\begin{bmatrix}
1 & 0 & 1 \\
1 & 1 & 1 \\
1 & 0 & 1
\end{bmatrix}
\]

can be represented as

\[ \{(0, 0), (2, 0), (0, 1), (1, 1), (2, 1), (0, 2), (2, 2)\} \]
Steps in digital image processing

- Two main types of image processing processes
  1. Both input and output of processing are images
  2. Inputs are images but outputs are some attributes of those images

- Image acquisition
  - Acquiring an image in a digital form
  - Could be acquired from a sensor or from a storage medium
  - May involve preprocessing such as scaling

- Image enhancement
  - Bring out obscured detail
  - Subjective method, depending on application
  - Contrast enhancement

- Image restoration
  - Objective method
  - Based on mathematical or probabilistic models of image degradation
  - Filling in the details, making the picture sharper

- Color image processing
  - Different color models for representation and processing

- Wavelets
  - Provide a foundation to represent images in multiple resolution levels
  - Useful for pyramidal representation and compression

- Compression
  - Techniques to reduce the storage required to save an image, or to conserve bandwidth required for transmission
  - Most common method of compression based on JPEG specification

- Morphological processing
  - Extracting image components useful in the representation and description of shape

- Segmentation
  - Partitioning an image into components, such as objects in the image
  - One of the most difficult tasks in image processing
  - Required for object recognition

- Representation and description
  - Boundary or region-based
  - Boundary representation good for external shape characteristics such as corners and inflections
  - Region representation appropriate for texture or skeletal shapes
  - Description, or feature selection, deals with extracting attributes to get some quantitative information of interest, and to differentiate between object classes
• Recognition
  – Assigning a label to an object based on its description
  – Knowledge about the problem domain
  – Building models of objects to be identified/recognized

• Image display

Components of an image processing system

• Sensor/digitizer
  – Sensor senses the energy radiated by the object to be captured
  – Digitizer converts the energy to digital form

• Specialized image processing hardware
  – Also called digital signal processor (DSP)
  – Used to achieve real-time frame processing (30 frames per second)
  – Older examples include Texas Instruments C80
  – Newer systems replace a specialized DSP with general purpose CPU such as PowerPC being used for its vector processing capabilities

• Software
  – Specialized modules to perform specific tasks
  – ImageMagick
  – OpenCV

• Mass storage
  – Images take up a lot of space
  – Consider storage requirements for $512 \times 512$ pixel color image
    * Assume 8-bits per color per pixel (normal)
    * Total memory needed: $512 \times 512 \times 3 = 786432$ bytes
    * On my machine, it gives me a $5.7'' \times 5.7''$ image
  – Short-term storage used during processing
    * Computer memory
    * Frame buffers
      · Allow access at video rates (30 fps)
      · Processed images are visible right away
  – On-line storage for relatively fast recall
    * Magnetic disk
  – Archival storage characterized by infrequent access
    * Magnetic tapes, CD-ROMs, jukeboxes

• Image displays
  – Monitors (CRT, plasma)
  – Stereo displays (require goggles)
• Hardcopy devices
  – Laser printers, film, inkjet printers

• Networking
  – Image transmission bandwidth
  – Good with broadband but consider data coming from Mars